Tumble Marination Strategies to Improve pH, Color, and Water Holding Capacity of Pale, Soft, and Exudative (PSE) Broiler Breast Fillets.

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A Thesis submitted in partial fulfillment of the Requirements for the degree of

Master of Science in Food Science and Technology

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April 16, 2003

Blacksburg, Virginia

Key Words: PSE meat, pH, color, water-holding capacity, marination, phosphates

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ABSTRACT:

Recently, there has been an increase in the incidence of pale soft and exudative poultry meat. Pale, soft, and exudative (PSE) meat is caused by a decline in pH early postmortem while carcass temperatures are still high. This decrease in pH leads to protein denaturation attributing to the pale color and poor water holding capacity (WHC) that is characteristic of this lesser quality meat. Pale, soft, and exudative meat has economic implications for processors with losses ranging between $2-4 million each year. Marination with salt and phosphates has been shown to improve protein functionality, thereby reducing lost meat yield and improving meat color, WHC, and texture. However, there are few studies relating marination with phosphates to improvements in PSE meat. Therefore, the purpose of this study was to determine if color, WHC, and texture improvements could be obtained in PSE meat via marination with various phosphate and NaCl treatments without altering the quality and oxidative stability of normal or PSE meat. In Experiment 1, 12 phosphates were evaluated for improvements in pH, color, and WHC of PSE meat. From these, five phosphates were chosen based on pH, color, and WHC improvements for Experiment 2. The marinades used in Experiment 2 increased the pH, decreased the L* values of the pale fillets, and improved water holding capacity. Thiobarbituric acid-reactive substances, sensory, and

microbial analysis studies concluded that marination with high pH phosphates can reduce the undesirable characteristics of PSE meat without increasing the development of oxidation, altering flavor, or reducing shelf-life.

ACKNOWLEDGEMENTS:

I would first and foremost like to thank my major professor, Dr. Christine Alvarado, for not only being an unconditionally helpful mentor but also a friend. Countless hours of her help and encouragement are what helped me achieve this goal in my life. I feel very blessed to have had the luck of choosing her as my graduate advisor at her brief stay at Virginia Tech. I would also like to thank my committee members Dr. Susan Duncan, Dr. Norman Marriott, and Dr. Robert Williams. I would like to thank Dr. Marriott for his personal words of support and encouragement and thank Dr. Williams for his patience in making my micro data presentable.

I would also like to thank my Mom, my sister Jennifer, and my wonderful close family for helping me through all the ups and downs of college life and for providing me with unwavering support in the belief of my abilities. I am very fortunate to have such as close and loving family. I feel unbelievably grateful to have such an absolutely wonderful mother who is also my best friend. Without her constant encouragement none of this would have been possible. I would also like to thank my little sister for being such as beautiful person who I also consider my best friend.

I would like to thank my boyfriend, Branden Sanders, for being a pillar of strength for me when I needed it the most and being my "work study" that would help me late into the night and on weekends until my project was complete. I am also grateful for his sense of humor that would carry me through countless hours of being covered in raw chicken and the rides on the "BT". Thank you for *always* being there.

The wonderful faculty and staff of the Food Science and Technology Department who made my many years here happy ones deserve thanks and recognition. I would like

to thank Dr. Wang for his selflessness and tremendous help and guidance throughout my graduate career. Thanks are due to everyone who made the long, early morning trips to the poultry plant with me: Dr. Wang, Dr. Alvarado, Harriet Williams, Kim Waterman, and Scott Daigle.

I would also like to thank my work study Daniel Schu who did the work "behind the scenes" as well as my fellow graduate students who became impromptu work studies Angie Hartman, Megan Hereford, Scott Daigle, Wes Schilling, and Donna Greene. I would like to acknowledge my statisticians Dr. Robert Schulman and Huizi Zhang, as well as Dr. Wes Schilling who has by default become the department's personal statistics consult!

Lastly, I would like to thank all the graduate students in the department for creating a fun environment to work in. I would especially like to thank Renee Raiden for being someone I feel connected with as a true lifelong friend. I would also like to thank Angie Hartman, Karol Gailunas, Megan Hereford, Joemel Quicho and Scott Daigle for being more than just officemates.

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Chapter 1

INTRODUCTION/JUSTIFICATION

Recently, the poultry industry has been faced with the increasing incidence of pale, soft, and exudative (PSE) meat. Pale, soft, and exudative meat has been associated with antemortem stressors such as rapid growth, extreme environmental temperatures, transportation stress, and preslaughter handling practices (McKee and Sams, 1998; Sams, 1999; Owens and Sams, 2000; Alvarado and Sams, 2002). Pale, soft, and exudative meat is the result of accelerated postmortem glycolysis and protein denaturation. The combination of rapid pH decline in postmortem muscle with high carcass temperatures early postmortem can lead to the development of meat with a pale color, low water holding capacity (WHC), and soft texture (PSE meat) (Barbut, 1993; Allen et al., 1998; Sams, 1999). Specifically, PSE meat causes an increase in purge resulting in reduced yield for processors. It has been estimated that PSE-like meat can cost a processor $2-4 million per year in lost meat yield alone; this does not include repackaging costs and labor (Alvarado, 2002). To be considered PSE meat the muscle must first be pale in color AND have a pH value of 6.0 or lower (Alvarado, 2002). PSE-like meat is meat that is subjectively evaluated based on color as being pale, soft, and exudative and has not yet been confirmed via pH tests.

There is a similar condition concerning PSE in pork. The genetic causes of PSE meat in poultry are not yet fully understood but the poultry industry is taking steps to determine how closely PSE development in pork is related to the same condition in poultry. The cause of porcine "stress susceptibility" is an inability to regulate the flow of

calcium ions in the different compartments of the muscle cell. Calcium is a key regulator of muscle contractions and relaxation; therefore, calcium imbalances can substantially alter muscle activity and energy metabolism. The cause of this imbalance in some swine is a genetic mutation. A single point mutation occurs in the calcium channel gate-keeper protein (ryanodine receptor, RyR) that controls the flow of calcium from storage compartments to the fluid surrounding the contraction proteins, actin and myosin (Sams, 1999). When this mutation in the amino acid sequence occurs, the protein gate leaks, or is even locked open, at which point the contraction apparatus is flooded with calcium, the metabolism accelerates, and body temperature rises (Sams, 1999).

The development of PSE meat is directly related to biochemical changes occurring in the muscle during rigor mortis development. The rate of pH decline is a determining factor in the development of meat with poor water holding capacity. A decrease in muscle pH can cause reduced net protein charge resulting in fewer charges to bind water (Sams, 1999). Also, the decline in pH early postmortem while carcass temperatures are still elevated can cause protein denaturation resulting in additional loss of WHC (Offer et al., 1991). Therefore, if the pH of PSE meat could be increased, WHC and yield may be increased.

Pale, soft, and exudative meat has been shown to cause the greatest problems in products to which no or low amounts of salt and phosphates are added (Sams, 1999). Marination of broiler breast fillets has been used as a means to improve protein functionality, flavor, and tenderness. Marinades containing salt and phosphates, specifically sodium tripolyphosphates (STPP), are the most common (Barbut et al., 1989). Both NaCl and STPP have been shown to improve WHC and yield (Hamm 1960;

Young and Lyon, 1986; Lemos et al., 1999). Salt and STPP used in marinades work synergistically to increase water binding by increasing pH and ionic strength as well as dissociating actinomyosin, which exposes more water binding sites (Wong, 1989).

However, phosphates vary in their solubility and effects on pH and water holding capacity. Therefore the extent of meat quality improvements are dependent upon which phosphates are incorporated. For example, pyrophosphates and diphosphates both promote myofibril swelling and extraction of myosin, but pyrophosphates are a more soluble form of diphosphates and hence are easier to use in typical processing conditions. Tetrasodium phosphates produce superior binding ability due to their high pH (approximately 11) while sodium acid pyrophosphate decreases pH, hence decreasing both WHC and yield. Short chain phosphates such as orthophosphates and pyrophosphates have the best buffering capacity (van Wazer, 1971).

If marination of broiler breast meat with high pH phosphates could be incorporated to increase ionic strength and increase the pH of the broiler breast meat with PSE-like characteristics, the loss to processors could be significantly reduced. Previous preliminary research (Woelfel and Sams, 2001; Alvarado and Sams) has indicated that the marination of broiler breast meat with high pH phosphates has improved the water holding capacity and color of pre-rigor and post-rigor PSE meat to that of normal meat. However, these studies did not include the effect of various other phosphates, sensory data, shelf-life analysis, and thiobarbituric acid-reactive substances (TBARS). Therefore, the focus of this experiment was to 1) determine which of a variety of phosphates selected would improve protein functionality in PSE meat; and 2) if marination with these phosphates alters quality parameters in both normal and PSE broiler breast meat.

Chapter 2

LITERATURE REVIEW

Rigor Development

The term rigor mortis is of Latin origin for "stiffness of death" (Hedrick et al., 2001). As energy reserves within the muscle become depleted postmortem (PM), the onset of rigor mortis is initiated in conjunction with the conversion of muscle to meat (Lyon and Buhr, 1999; Hedrick et al., 2001). Muscle stiffening due to rigor mortis is caused by the formation of permanent cross-bridges in the muscle between actin and myosin filaments (Hedrick et al., 2001). Actin and myosin are the two most important myofibrillar proteins. They comprise over half of the protein of the skeletal muscle and are major factors in PM onset and resolution of rigor.

Both contraction and relaxation of living muscle requires energy in the form of adenosine triphosphate (ATP) (Pearson and Young, 1989; Lawrie, 1991; Ganong, 1995; Guyton and Hall, 1996; Hedrick et al., 2001). However, unlike in the living muscle, relaxation cannot occur post rigor because there is no energy available in the form of ATP to break the actinomyosin bonds (Hedrick et al., 2001).

This lack of energy is because the stores of creatine phosphate used for the phosphorylation of ADP to ATP are small and cannot be maintained in PM muscle cells for longer than a few minutes without regeneration (Lehninger et al., 1993; Ganong, 1995; Lyon and Buhr, 1999; Hedrick et al., 2001). As creatine phosphate stores are exhausted, the phosphorylation of ADP is insufficient to keep muscle tissue in a relaxed state (Hedrick et al., 2001).

In order for ATP to be regenerated PM, the cellular metabolism must shift from aerobic to anaerobic pathways (Lyon and Buhr, 1999). Muscle glycogen becomes rapidly utilized once metabolism is shifted to anaerobic pathways, resulting in the accumulation of lactic acid as a waste product (Lyon and Buhr, 1999). In living muscle, the lactic acid produced is carried by the blood from the muscles either to the liver, where it is resynthesized into glucose, or to the heart where it becomes carbon dioxide and water. However, upon exsanguination, the circulatory system is no longer available to transport the lactic acid and it remains in the muscle tissues, increasing in concentration as metabolism continues (Hedrick et al., 2001).

The amount of glycogen in muscle tissue at the time of death determines the magnitude of lactic acid accumulation and pH decline (Lehninger et al., 1993; Lyon and Buhr, 1999). As lactic acid increases in the muscle, pH begins to decrease from 7.1, to approximately 5.87 which is inhibitory to glycolysis (McGinnis et al., 1989). When all phosphorylating stores are diminished, and ATP can no longer be formed from ADP, the muscle becomes nearly inextensible, and rigor mortis is complete (Lawrie, 1998; Hedrick et al., 2001). The permanent actinomyosin cross-bridges that form as a result of rigor mortis contract the muscles and shorten sarcomere lengths, thereby increasing tension (Hedrick et al., 2001).

The calcium pump is responsible for transporting calcium ions from the sarcoplasmic reticulum to the myofibrillar proteins, actin and myosin, in order to cause muscle contractions. Without ATP, the actinomyosin cross-bridges cannot be broken because there is no ATP remaining to power the calcium pump, and muscle contractions can no longer occur (Mickelson and Louis, 1993; Hedrick et al., 2001).

Resolution of rigor occurs when the muscle ultrastructure is degraded, specifically the rupture of the actin-Z-disc connection (Lyon and Buhr, 1999). It is thought that since the sarcoplasmic reticulum and mitochondria can no longer hold calcium, the calcium is released into the muscle cell and reaches high enough levels to induce the cleavage of the actin-Z-disc complex (Greaser et al., 1969) through activation of the calpain enzymes. This rupturing causes a gradual loss of ability for the muscle to maintain isomeric tension due to loss of Z-disc integrity within the muscle fiber, and it is associated with increased tenderness (Lyon and Buhr, 1999).

Meat Quality Characteristics

Problems in meat quality are primarily caused by changes in the biochemistry and morphology of the muscles themselves (Sosnicki, 1993). These biochemical changes postmortem can affect important quality attributes of poultry muscle, such as tenderness, flavor, and texture (Barbut, 1993). Meat quality is influenced by several factors, including: circumstances of death, rate of PM glycolysis, simultaneous decrease of ATP and pH, time and temperature at onset of rigor and the resulting degree of muscle shortening (Lister et al., 1970; Ferket and Foegeding, 1994; Pearson, 1994).

Proteins are the principal functional and structural components of processed meats and are therefore responsible for the characteristic handling, texture, and appearance of these products (Hermansson et al., 1986). The "physicochemical properties" of these proteins affect the proteins' behavior in food systems during preparation, processing, storage and consumption, and contribute to the quality and organoleptic attributes of a food system (Kinsella, 1982).

The effect of muscle pH is critical to several quality characteristics of meat such as color, water holding capacity (WHC), toughness or texture, cook loss, juiciness, and microbial stability and has been reviewed by Fletcher (1995), Allen et al. (1998), Lyon and Buhr (1999), and van Laack et al (2000). The relationship between the rate of pH decline and the resulting meat quality is a function of the temperature of the muscle when a pH of 6.0 is reached. Temperature has a discernible influence on the rate of pH decline; high temperatures accelerate pH decline, whereas low temperatures hinder rates of glycolysis and decrease lactic acid production. Higher muscle temperatures and corresponding lower pH values result in an earlier onset of rigor mortis as well as a greater degree of rigor shortening.

Color

When considering the three major food quality attributes, color, flavor, and texture, color may be the most important and has been extensively reviewed by Barbut (1993), Kauffman et al. (1993), and Fletcher (1999). Color is a complex term not easily defined. The American Heritage College Dictionary (2000) defines color as "that aspect of things that is caused by differing qualities of the light reflected or emitted by them, definable in terms of the observer or the light." Appearance is one of the most important quality attributes of a meat product and is often critical for both the initial selection of a product as well as final consumer evaluation.

Color is the major contributing factor to the appearance of poultry meat. Consumers are often willing to pay a premium price for quality; therefore the economical importance of acceptable color is obvious. Color is the key visual stimulus involved in

the selection of a food. If color is unacceptable to the consumer, the product will not be considered further for purchase. Once selected, color remains important to the eventual acceptance or rejection of the food upon consumption, and can also cast a halo type effect on the perceptions of other major sensory attributes.

When considering actual meat color, the principle issues are muscle type (light versus dark meat), color variation, and color defects. The most common color problems associated with breast meat can be related to extremes of paleness (PSE-like condition) and darkness, which fall under the category of color defects, when viewed in direct comparison with similar products. For example, variation in breast meat color in multiple-fillet packages illustrates how noticeable differences in color can be important.

The major variables affecting poultry meat color can be divided into three contributing factors: myoglobin content, the chemical state and reactions of the myoglobin, and meat pH. Myoglobin content is primarily related to species, muscle, and age of the animal; whereas the chemical state and reactions of myoglobin with other compounds greatly affect meat color. However, in broiler and turkey breast fillets myoglobin does not play a significant role in color determination since they are considered glycolytic muscles (Hedrick et al., 2001).

The amount of lactic acid accumulation within the muscle, and the resultant muscle pH are highly correlated to meat color (Allen et al., 1998; Barbut, 1998; Fletcher, 1999; Owens and Sams, 2000; van Laack et al., 2000; Woelfel and Sams, 2001; Alvarado and Sams, 2002). Higher muscle pH results in darker meat whereas lower muscle pH values are linked with lighter meat. The extremes of poultry meat color are referred to as

either dark, firm, and dry (DFD) having high meat pH, or PSE, resulting in lighter meat and lower pH values (Fletcher, 1999).

The extremes of poultry meat color can also be explained by muscle water content and location, and its consequent alteration of light reflectance (Hedrick et al., 2001). The paleness of PSE meat can be largely attributed to the low pH causing a high proportion of free water between the muscle cells rather than within them (van Laack and Lane, 2000; Hedrick et al., 2001). Tissues containing a large amount of this extracellular water have many reflecting surfaces that completely reflect light, but have only a limited number of surfaces capable of light absorption, and the meat appears pale (Hedrick et al., 2001). In DFD meat, the opposite phenomenon occurs. Instead of large amounts of extracellular water, the tissues have large amounts of intracellular water due to the darker meat's higher pH and therefore greater water-binding ability. As a result, color absorption is enhanced and white light reflection is minimized, making the meat appear dark (Hedrick et al., 2001).

Water Holding Capacity

Water holding capacity (WHC) is the ability of meat to retain its water during application of external forces such as cutting, heating, grinding, or pressing (Hedrick et al., 2001). Water holding capacity is at least partially responsible for many of the physical properties of meat, including color, texture, and firmness of raw meat, and juiciness and tenderness of cooked meat and has been reviewed by numerous researchers (Barbut, 1997; Allen et al., 1998; van Laack et al., 2000; Hedrick et al., 2001).

Water exists in one of three forms, bound, immobilized, or free (Honikel and Hamm, 1994; Hedrick et al., 2001). Water is a charged, or polar, molecule and associates with the electrically charged reactive groups of muscle proteins. Four to five percent of the total water in muscle exists in this state, known as bound water, where water molecules are very closely associated with the charged reactive groups. This water remains tightly bound to the protein reactive groups even during the application of severe mechanical or other physical force. Immobilized water is attracted to these bound molecules, but the attractive forces are weaker, and become increasingly weaker the further away the water is from the reactive groups on the proteins. The quantity of immobilized water is dependent upon the amount of physical force exerted on the muscle. Water that is held on only by weak surface forces is known as free water and can be easily removed with little physical force such as the shrinking of myofibrils during rigor mortis development.

The number of reactive groups on muscle proteins and their availability for binding water is influenced by several factors (Hedrick et al., 2001). In the immediate surroundings of .proteins, these conditions are largely consequences of postmortem changes, namely, lactic acid production, loss of ATP, onset of rigor mortis, and changes of cell structure associated with proteolytic enzyme activity (Hedrick et al., 2001). The conversion from aerobic to anaerobic metabolism following exsanguination results in the accumulation of lactic acid and a coinciding drop in pH, which is responsible for an overall reduction in the number of reactive groups on proteins available for water binding (Hedrick et al., 2001).

The number of reactive groups is reduced because, as the pH drops, it approaches the isoelectric point (pH < 5.4) of myofibrillar proteins. Consequently, the reactive groups tend to be attracted to each other instead of water since the number of positively and negatively charged groups is equal, thus decreasing the number of reactive groups to bind to water (Bendall, 1964; Pearson and Young, 1989; Lawrie, 1998; Hedrick et al., 2001). This influence of pH is referred to as the net charge effect (Swatland, 1993; Lawrie, 1998; Hedrick et al., 2001). As pH values increase, a greater net charge exists on the protein, and the muscle can hold greater amounts of bound or immobilized water (Hedrick et al., 2001).

Research has shown that decreases in pH values in normal meat account for only about one-third of the loss of WHC postmortem (Hedrick et al., 2001). The remaining cause of reduced WHC is known as the steric effect, or lack of interstitial space to bind water and has been reviewed by Swatland (1993), Lawrie (1998), and Hedrick et al. (2001). When there is little net charge on the proteins, there are few charged groups available to separate protein chains by repulsive forces. Bound groups are prevented from binding water, allowing protein chains to pack closely together, further preventing those available reactive groups from binding water.

Tenderness & Texture

Tenderness is one of the most important meat quality characteristics. Consumer trends have shifted from the purchase of whole carcasses to more value added products such as parts and deboned products. Previously, poultry meat was associated with the term “tender” and there were few complaints about tough breast meat, because muscle

completed rigor while on the bone (McKee and Sams, 1998; Young and Lyon, 1997; Lyon and Buhr, 1999). As the demand for further processed poultry products increased, especially boneless breast meat, the industry was propelled into expansion, but tender meat was no longer guaranteed due to required pre-rigor boning time (Lyon and Buhr, 1999).

Muscle pH, aside from affecting meat color and water holding capacity, is also very influential on meat texture. The PM rate of pH decline in the muscle substantially affects meat texture (Barbut, 1993; Allen et al., 1998; Lyon and Buhr, 1999). Binding properties and moisture characteristics of cooked meat are also dependent upon muscle pH levels (McKee and Sams, 1998; Lyon and Buhr, 1999; Alvarado and Sams, 2002). The extent of muscle contraction at the onset of rigor is variable, influenced by several physiological pathways and processing procedures such as early deboning, and is primarily responsible for meat tenderness (Lyon and Buhr, 1999).

The turkey industry has reported an increased incidence of formed turkey breast loaves with poor texture and excessive exudative meat characteristics (McKee and Sams, 1998). High quality meat in terms of texture and WHC will better retain added moisture and stay firm when processed into products such as turkey rolls (Barbut, 1997). When pH is abnormally low early postmortem and carcass temperatures are still high, the proteins responsible for firm gels (specifically myosin) are denatured causing a softer meat texture. This softer texture is also a result of a decreased WHC leading to poor protein function that causes poor cohesion of meat pieces in formed products (Sams, 1999). This poor binding and fragmentation, or “cracking” in formed deli loaves results in poor sliceability of deli meats as well as consumer dissatisfaction.

Pale, Soft, and Exudative Meat

Pale, soft, and exudative meat, otherwise referred to as PSE meat, is meat that is characterized by pale color, soft gels, poor water holding capacity, and exhibits substantially reduced cook yield (Wismer-Pendersen 1959; Briskey 1964; Topel et al, 1976; Smith and Lesser 1982; DeSmet et al, 1996; McKee and Sams, 1998; Sams, 1999; Alvarado and Sams, 2002). Pale, soft, and exudative meat was first recognized in pork, and more recently a similar condition has been observed in poultry meat. The commercial incidence of PSE meat in poultry ranges from 5 to 40 percent and is highly dependent on seasonality (Barbut, 1996; McKee and Sams, 1998; Owens et al., 1998; Woelfel et al., 2002).

The primary cause of financial loss due to PSE meat is due to excessive water loss and reduced protein functionality in affected meat products (Strasburg, 2000). This defective meat can, in extreme cases, produce up to 20 percent purge loss in a cook in bag and cook losses of over 30 percent from a broiler breast fillet (Sams, 1999). Poor quality meat due to increased water loss in cook-in bag products such as deli loaves and rolls results in product with a dry texture that is unacceptable to the consumer (Woelfel and Sams, 2001). Pale, soft, and exudative meat's poor protein functionality also results in poor binding of meat pieces in formed products, such as loaves and rolls, and is termed "cracking" (Ferket and Foedgeding, 1994; McKee and Sams, 1998; Sams, 1999).

There are many factors which are believed to lead to PSE meat in poultry, both genetic and environmental. Some of these factors are altered regulation of intracellular calcium as well as antemortem stresses, such as transportation stress and environmental temperatures (Sams, 1999).

The inability of an animal to tolerate stress results in PSE meat (Sams, 1999; Owens and Sams, 2000; Alvarado and Sams, 2002). PSE meat seems to be caused by failure to regulate calcium flow in the sarcoplasmic reticulum (Sams, 1999). Calcium is a key regulator of muscle contraction and relaxation, therefore, calcium imbalances can drastically alter energy metabolism and muscle activity (Sams, 1999). Intracellular calcium stimulates glycolysis, which generates heat and lactic acid in skeletal muscle (Ebashi and Endo 1968; Sams, 1999). This increase in lactic acid due to calcium influx and increased glycolysis results in a rapid pH drop early postmortem while muscle temperatures are high, and is partially responsible for the development of PSE conditions (Lyon and Buhr, 1999).

The genetic causes of PSE meat in swine have been extensively studied. There is a single point mutation in the ryanodine receptor (RyR), the calcium channel gate keeper protein, that controls calcium flow from storage compartments to the fluid surrounding the contraction proteins, actin and myosin (Fuji et al., 1991; Mickelson and Louis, 1993; Sams, 1999). This point mutation in the amino acid sequence causes the protein gate to leak, or in extreme cases, to become locked open (MacLennan and Phillips, 1992; Sams, 1999). When this genetic mutation is present, the muscle cell is flooded with calcium, thereby accelerating metabolism and leading to rises in body temperature (Louis et al., 1993; Sams, 1999).

The genetic effects of stress on poultry are much more complicated to study than swine because poultry have two RyR isoforms in skeletal muscle, each with two copies that can be independently normal or defective (Sams, 1999). This greatly increases the number of potential combinations of normal and defective proteins (Sams, 1999). If a

broiler has some of its RyR proteins functioning properly, it might be able to tolerate stress; however, if enough RyR gate keeper proteins are defective, stress could trigger an increase release of calcium resulting in the development of PSE meat (Sams, 1999).

Reports of PSE turkey and broiler meat have increased in concert with intensive genetic selection for lean, heavily muscled, rapidly growing turkeys (Toelle et al., 1991). The rate of early postmortem pH decline is anywhere from 1 to 4 times faster in rapidly grown turkeys compared to slower growing breeds (Sante et al., 1991; Barbut, 1997). In these rapidly growing turkeys, muscle fibers increase in size relatively faster than the connective tissues and capillaries, which can lead to fiber necrosis and/or loss of connective tissue integrity (Sosnicki, 1993). This condition, also termed focal myopathy, may adversely affect cohesiveness, tenderness, and juiciness of processed turkey breast meat (Grey, 1989). It has also been shown that the outgrowth of turkey breast muscle fibers over the supportive connective tissues may predispose products to fragmentation and poor cohesion (Swatland, 1990).

Decreased physical activity due to sedentary growing conditions along with a low capillary to muscle fiber ratio causes localized muscle microischemia, one possible cause of focal myopathy (Sosnicki, 1993). Microischemia causes a high rate of lactic acid production promoting localized muscle acidosis because there is not enough blood circulating through the muscle (Sosnicki, 1993). Muscle acidosis combined with a decrease in energy production of free radicals via reduced mitochondrial respiratory control, typically results in the degradation of muscle cell membranes and irreversible cell injury (Sosnicki, 1993). This same trend can be observed in broilers.

In 1950, a 12-week period was required to reach the slaughter weight for broilers of 1.8-2.0 kg, and now less than six weeks is required (Lilburn, 1994). This selection for larger, faster growing birds has been theorized as a cause of PSE meat (Sams, 1999; Owens and Sams, 2000). This is explained by the multiple structural abnormalities that occur in fast growing birds, such as capillary insufficiency, that results in decreased muscle integrity (Sosnicki and Wilson, 1991; Sams, 1999).

Preslaughter handling practices also have a huge influence on the development of PSE meat in poultry. Preslaughter handling has the potential to influence several important quality characteristics of the lean meat, either through influencing acidification, or rigor development (Warriss et al., 1992; Owens and Sams, 2000; Alvarado and Sams, 2002). Preslaughter handling can deplete muscle glycogen stores, thus influencing the rate and extent of acidification (Warriss et al., 1992). The extent of struggling at death accelerates the rate of PM glycolysis due to muscle temperature elevation, resulting in a more rapid consumption of glycogen, lower initial pH, and an earlier onset of rigor mortis development (Dodge and Peters, 1960; de Fremery and Lineweaver, 1966; Lawrie, 1998; Hedrick et al., 2001). Exposure to heat or cold stress, or confining turkeys in cages during transport may enhance local ischemia of the breast muscle, glycolytic metabolism, and accumulation of lactic acid resulting in a dramatic decrease of pH in muscle fibers and blood (Froning et al., 1978; Mills and Nicoli, 1990). This theory has been confirmed by Sosnicki and Wilson (1991) who showed that turkeys not exposed to preslaughter handling had significantly higher pH and ATP levels and lower lactic acid content compared to birds that had been exposed to 12 hours of preslaughter transportation.

Stress directly before and during slaughter has been shown to affect meat color (Froning et al., 1978). Froning et al. (1978) reported that turkeys affected by temperature stress and excitement prior to slaughter had an accelerated pH decline and paler, tougher meat compared to turkeys that were not susceptible to stress. It has also been observed that broilers entering the processing plant are sometimes slaughtered in a highly excited state, which profoundly affects the quality of their meat (Sams, 1999). Preslaughter stress accelerates the metabolic rate, which in turn accelerates the rate of muscle pH decline during rigor mortis (Sams, 1999). This abnormal decrease in pH (<5.8) early postmortem combined with high carcass temperatures (>35 C) leads to the denaturation of the muscle proteins that are primarily responsible for color and water holding capacity of the meat (Sams, 1999).

Khan and Frey (1971) and van Hoof (1979) indicated that both ante- and postmortem stresses combined with variation among birds can contribute to large differences in the rate of rigor mortis completion. Barbut (1993) performed a similar study and concluded that the apparent pale color in poultry meat is associated with lower pH values and PSE-like conditions. L* value is a measure of lightness of the fillet with higher numbers indicating increased lightness. In these studies, L* value of the meat was significantly negatively correlated with pH, indicating that pH decreased as paleness increased. The same type of relationship was found between L* value and water holding capacity, with paler meat having lower WHC as well as lower pH values (Allen et al., 1998; Barbut, 1998; Owens and Sams, 2000; van Laack et al., 2000; Woelfel and Sams, 2001; Alvarado and Sams, 2002). The less functional proteins of the PSE meat also showed that as cooking loss increased, gel strength decreased.

Phosphates

Phosphates are often used as food ingredients that perform several functions in a wide variety of foods and have been extensively reviewed by Dziezak (1990) and Molins (1991). Phosphates can be grouped into two categories: orthophosphates and condensed phosphates. Orthophosphates are the larger of the two categories and are considered to be the most important to the food industry. Orthophosphates consist of one phosphorous atom tetrahedrally surrounded by four oxygen atoms. This class of phosphates has three valences that can be filled by hydrogen atoms, alkali metal cations, or a combination of the two to create mono-, di-, or tribasic orthophosphates.

The other category of phosphates known as condensed phosphates are produced by heating mixtures of orthophosphates under controlled conditions and are composed of two or more phosphorous atoms linked via shared oxygen. Condensed phosphates include polyphosphates (straight-chained) and metaphosphates (rings). Polyphosphates can be further broken down based on chain length into pyrophosphates (two phosphorous (P) chain), tripolyphosphates (three P chain) and long-chain polyphosphates (four or more P atoms).

Pyrophosphates and tripolyphosphates are crystalline materials whereas long-chain polyphosphates are amorphous or glass materials created from a mixture of many polyphosphates of varying chain lengths (Ellinger, 1977). Over time, long-chain polyphosphates hydrolyze into orthophosphates, pyrophosphates, and tripolyphosphates (Ellinger, 1972). Metaphosphates are pure crystalline compounds composed of six or eight membered rings that find only limited use in the food industry. Ultraphosphates are

another group of phosphates that are branched chains or rings and find even less applications in the food industry.

Phosphates as a group contain certain chemical properties that enable them to produce a wide variety of effects in food systems. Some of these effects are buffering and pH control, inactivation of metal ions, and polyvalency and polyelectrolyte behavior. Certain phosphates are able to maintain a constant pH after the addition of either acids or bases to a system and are considered to be good buffers. Mono- and disodium phosphates and sodium acid pyrophosphate have the best buffering capacity for the pH ranges of 2 to 3, 5.5 to 7.5, and 10 to 12, respectively.

Another contribution of phosphates has been to increase or decrease pH to desired levels. Acidic phosphates such as monosodium phosphate, monoammonium phosphate, and sodium acid pyrophosphate have been used to decrease pH levels. Alkaline phosphates such as di- and trisodium phosphates, sodium tripolyphosphates, and tetrasodium pyrophosphates are commonly used to increase pH levels.

The incorporation of phosphates can chelate metal cations such as calcium, magnesium, copper and iron by either sequestering or precipitating them. Phosphates sequester metal ions by forming a soluble complex with the cations, allowing the metals to remain in the food system yet are rendered incapable of interfering with food processing reactions. Hexametaphosphates and sodium tripolyphosphates best sequester alkaline earth metal cations such as calcium and magnesium, whereas iron and copper cations are most effectively sequestered by short-chain polyphosphates. Orthophosphates can be used in high concentrations to precipitate metal cations that can be removed from the food system as an insoluble salt.

Phosphates are termed polyvalent anions in solution because they have more than one negative charge. Orthophosphates can have up to three negative charges, depending on pH, and polyphosphates can be even more anionic. On account of this highly charged nature, polyphosphates are able to interact with a variety of food constituents to produce many beneficial results. Polyphosphates have the ability to become sorbed onto surfaces of certain constituents and affect the surface charge, consequently promoting deflocculation, dispersion, emulsification, or suspension of the constituent (van Wazer, 1971). Polyphosphates also display polyelectrolyte behavior, which allows them to attach themselves to positively charged sites of large molecules such as proteins thereby increasing water binding and gel formation of the proteins as well as increasing protein solubility (van Wazer, 1971).

Sodium tripolyphosphates are the most widely used of the phosphates in the meat industry, accounting for nearly 80% of the phosphates incorporated either as a single phosphate or a blend (Barbut et al, 1988). Phosphate addition to poultry meat promotes water retention, retards oxidative rancidity and the resulting off-flavors, decreases loss of protein containing juices when frozen meat is thawed, and reduces shrinkage when meat is cooked.

Marination

Marination of poultry breast meat continues to increase as the demand for further processed products increases (Lyon et al., 1998). Marinades can be incorporated into meat by tumbling, mixing, or massaging the meat at low temperatures, thereby facilitating tenderization through disintegration of the muscle fiber sheath and stretching

of the myofibrils (Brandt, 2001). There are several commercial methods used to marinate meat including tumbling, blending, and injection. Each method has its advantages and disadvantages. Tumbling promotes rapid and consistent pickup at controlled temperatures, the ability to marinate large quantities, and the capability to handle many different products and sizes (Smith, 1999). Blending allows for finer control of product mixing as compared to tumbling, and the ability to directly apply refrigerant. Injection marination is beneficial for its relative consistency of marinade application on large and complex products, and reduction of labor and speed of marination (Smith, 1999).

The key ingredients in poultry marinades are salt and phosphate. Marination with a variety of combinations of salt and phosphates has been used as means to improve taste, tenderness, and protein functionality of broiler breast fillets (Alvarado and Sams, 2002). Marination has also been used to improve protein functionality losses imparted by the PSE condition (Woelfel and Sams, 2001).

One of the most important properties of poultry meat is its water holding capacity which is defined as the ability to bind and retain innate water, as well as added water during marination (Toledo, 1999). Pale, soft and exudative meat has poor water holding capacity which results in an economic loss for processors, as well as a decrease in consumer acceptance. Marination has been used as a method to increase the water holding capacity, thereby improving the quality and increasing the yield of the meat. This increase in functionality is due to the marinade solution maintaining a higher postmortem pH (Xiong et al., 2000).

Myofibrillar proteins, such as actin, myosin, and the actomyosin complex, are primarily responsible for WHC and marinade pick up and retention (Toledo, 1999). The

salt and sodium tripolyphosphates commonly used in poultry meat marination work synergistically to increase water binding by increasing pH and ionic strength, combined with the dissociation of actomyosin, exposing more water binding sites (Wong, 1989; Pearson and Gillett, 1999). Basically, the salt and phosphate marinade uptake causes the tissue fibers to swell, resulting in decreased cooking loss and increased juiciness and tenderness of the meat (Xiong et al., 2000; Brandt, 2001).

Salt can affect meat proteins in many ways. At a low concentration, salt increases the WHC of proteins due to hydrated salt ions binding to charged groups of proteins (Damodaran, 1996). This resultant increase in water binding can be attributed to the water associating with bound ions. When salt binds to proteins electrostatic repulsion causes the protein structure to loosen and allow more water binding (Damodaran, 1996). Salt also increases marinade pick-up by solubilizing the actin and myosin proteins which increases the space between the thick and thin filaments to pick up and retain marinade solution.

Phosphates can increase meat pH, thereby increasing WHC due to higher pH values caused by charged proteins. An increased WHC allows for better uptake and retention of the marinade solution itself, as well as increasing the retention of the meat's own moisture, consequently increasing yield in an inexpensive manner (Smith, 1999).

Xiong et al. (2000) studied the effect of various polyphosphate and salt (NaCl) solutions on myofibril protein extraction. In the absence of phosphates, no significant swelling or any other changes were noted at salt concentrations of 0.4 M or less. When salt concentrations were increased to 0.5 M and 0.6 M myofibrils started to enlarge transversely and protein extraction became significantly noticeable.

The addition of polyphosphates induced change in the protein extraction pattern. It is thought that polyphosphates possess an ATP-like property that allows it to extract myosin and disintegrate the A-band from the outside of the thick filaments (Xiong et al., 2000). Actomyosin is formed during rigor mortis and creates a state of permanent muscle contraction that leads to tough meat. Polyphosphates have the ability to dissociate this actomyosin complex, enabling myofibril lattices to expand laterally, resulting in an increase in water uptake (Xiong et al., 2000).

Tripolyphosphates were also shown to have similar effects. Xiong et al. (2000) concluded that both poly- and tripolyphosphates are ionic species that dissociate myofilaments, depolarize thick filaments, and remove the actomyosin structural barricade, thereby enhancing cooking yield and juiciness.

Other research has demonstrated that using high pH phosphate marinades and sodium bicarbonate can increase the pH and improve WHC in pale meat to that of normal meat (van Laack et al., 1998; Woelfel et al., 2002). Marination with sodium bicarbonate has also been studied in the prevention of rapid pH decline early postmortem decreasing the incidence of PSE meat (van Laack et al., 1996; Kauffman et al., 1998; van Laack et al., 1998). Woelfel and Sams (2001) concluded that marination in salt and alkaline phosphate solution at pH 9 improved water holding capacity of pale fillets and partially restored protein functionality to that of its normal meat counterparts.

Need for Research

Processors in an average size plant lose anywhere from two to four million dollars a year in lost meat yield alone due to the PSE condition of broiler meat (Alvarado, 2002). These costs do not include the materials and labor required for repackaging. Some losses are still unaccounted for because they are "hidden" to the processors. For example, drip loss during processing is not visible but decreases meat yield nevertheless. Also the multiplier effect, when a PSE fillet is used in more than one product, causes poor meat quality in all products affected. Poor meat quality ultimately results in consumer dissatisfaction and/or a loss of repeat buyers. A remediation technique needs to be found that can rectify poor meat quality caused by the PSE condition. Marination of PSE meat with a combination of salt and phosphates has been shown as one possible method of improving the quality of PSE meat. Therefore, this research was conducted to find a marinade that would improve the quality of PSE meat to that of normal meat in hopes of reducing significant product losses caused by the PSE condition.

Chapter 3

MATERIALS AND METHODS

Experiment 1

Tumble Marination

Post rigor PSE and normal broiler breast fillets were collected in two separate trials (n=144 each collection) from the deboning line of a commercial processor. Broiler breast fillets were screened using L*[1] values to categorize the tissues as PSE or normal fillets. The fillets were considered to be PSE if they had an L* value of 57 or higher and normal if the L* value was less than 53. The pH[2] values also were taken upon initial collection. The fillets were tagged[3], bagged, and placed on ice for transportation back to the Virginia Tech Muscle Foods Laboratory. Transported PSE and normal fillets were placed in a 4 C cooler overnight.

The weight of each fillet was recorded the following day. The samples then were divided into 12 groups, each including 6 PSE and 6 normal fillets. The total weight of each group was calculated and a 20% marinade (wt/wt) was made with 94.25% water, 2.25% phosphate, and 3.50% salt, with a final concentration of 0.45% phosphate and 0.70% salt in the breast meat. Pale and normal fillets were placed separately into a tumbler[4] along with the marinade solution. The fillets were tumble marinated at 65-70 mm Hg for 30 minutes at 12 RPM.

The following phosphates were tested:

1. pH 11.9
2. pH 9.7 (industry standard)

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[1] Minolta chroma-meter CR-300 Series Osaka, Japan
[2] Handheld pH/mV/temperature meter Model IQ150 Scientific Instruments, Inc. San Diego, CA
[3] Avery Dennison Mark III Heartland Swiftack™ for Poultry Fair Play, MO
[4] Original Inject Star ® 20L Tumbler Brookfield, CT

3. pH 7.0
4. pH 9.0
5. pH 8.5
6. pH 9.0
7. pH 9.8
8. pH 9.5
9. #3 standardized to pH 11
10. #4 standardized to pH 11
11. #5 standardized to pH 11
12. #8 standardized to pH 11

After tumble marination, each fillet was weighed again to determine marinade pickup (%). The fillets then were placed in a covered container in a 4 C cooler for either 3 or 24 h to allow for marinade equilibration. After 3 h of equilibration, half of the pale and half of the normal marinated fillets of each group were again weighed to determine marinade retention (%) using the following equation:

$$\frac{\text{Post-marination fillet weight} - \text{Pre-marination fillet weight}}{\text{Post-marination fillet weight}} \times 100$$

L* values and pH values again were recorded for each fillet. Samples were placed on aluminum-lined pans on raised wire racks. A thermocouple was inserted into the thickest portion of each fillet and the pan covered with raised aluminum foil such that no foil touched the samples. Fillets were cooked in a convection oven[5] to an internal temperature of 73 C. Cook loss (%) was determined after cooling fillets to room temperature prior to weighing according to Sams (1990).

Total moisture was also determined using the procedure of Urbin et al. (1962). Three to five grams of cooked center cut fillet pieces were placed in pre-weighed aluminum pans[6] and dried in a drying oven[7] overnight. The following day, all aluminum

[5] Solid State Mark V convection oven G. S. Blodgett Corp. Burlington, VT
[6] Aluminum weighing dish w/ handle 42 mL Cat# 08-732, Fisher Scientific
[7] Blue M Electric Company Oven Model # OV-490A2 Blue Island, IL

plans were placed in a dessicator for one hour and weighed. These procedures were repeated with the remaining fillets that were allowed to equilibrate in a 4 C cooler for 24 h to determine any differences in equilibration of marinade over time.

Of the 12 phosphate treatments used, three were selected based on improvements in WHC, L* value, and pH of the pale fillets. These three phosphates along with an industry standard (sodium tripolyphosphate pH 9.7) and a newly formulated phosphate (STPP blend standardized to pH 11) were used in Experiment 2 for a total of five phosphates.

Experiment 2

Both PSE and normal fillets were collected at deboning from a commercial processor and transported back to the Virginia Tech Muscle Foods Laboratory as in Experiment 1. Fillets were marinated with a 20% (wt/wt) NaCl and phosphate solution as described in Experiment 1 using marinades 1 (pH 11.9; monophosphate (MP)), 2 (pH 9.7; sodium tripolyphosphate (STPP), an industry standard), 4 (pH 9.0; hexametaphosphate (HMP) and STPP), 6 (pH 9.0; HMP and STPP; agglomerated (agg)), and 13 (pH 11.0; HMP, STPP, and MP; a newly formulated marinade).

The broiler breast fillet samples in Experiment 1 were left to equilibrate for either 3 or 24 h to determine differences in equilibration. No differences were found between equilibration times; therefore, in Experiment 2, all fillets were placed in a 4 C cooler overnight. Time from marinade to cook was standardized to 24 h. The samples were cooked in a convection oven as described by Sams (1990); cook loss was determined.

Thiobarbituric Acid Reactive Substances

A modified method for thiobarbituric acid reactive substances (TBARS), as described by Spanier and Traylor (1991), was performed on fillets at 0, 2, and 4 days after cooking. On day 0 (day cooked) one-third of the fillets were immediately sealed in a plastic bag and stored at -78 C for up to a week until analysis. The remaining fillets were tray-packed and stored in a 4 C cooler until day 2 or 4 at which time they were sealed in a plastic bag and stored at -78 C for up to a week until analysis. Estimated TBARS values of stored cooked meat tend to be high, therefore a standard curve was prepared with 0.0, 2.5, 5.0, 7.5, and 10.0 ml of standard TMP (99% tetramethoxypropane, Sigma Chemical Company) solution. The fillets were thawed, and minced. Each sample (5.0 ± 0.1g) was homogenized[8] with distilled water (85 ml), 0.1 ml of 10% sodium dodecyl sulfate (SDS), and 10.0 ml of antioxidant (propyl gallate) and chelator (ethylenediaminetetraacetic acid) solution. All samples and standards were placed in ice until all homogenization was complete. Homogenate was stirred with a glass bar and 1.0 ml of each sample homogenate and standard solution was transferred to 15 ml centrifuge tubes. Four milliliters of solution I (0.375% TBA, 0.506% SDS, and 9.370% acetic acid adjusted to pH 3.4) was added to each tube, mixed, capped loosely, and incubated in a water bath (95 C) for 60 min. Tubes were cooled and 1.0 ml of water (4 C) and 5.0 ml of solution II (15:1 n-butanol and pyridine) was added to each tube and mixed under a hood for approximately 10 sec. Tubes were centrifuged at 25 C at 3500 rpm for 15 min. The top layer was pipetted off and the absorbance of the organic solution was read at 532 nm[9]

[8] Virtis Company Virtishear Cat# 225318 Gardiner, NY
[9] Milton Roy Company Spectronic 21D Rochester, NY

under a hood. Time from cook to freeze until TBARS was conducted was standardized to 1 h.

Sensory Evaluation

Cooked fillets were evaluated by an untrained consumer sensory panel to determine overall preference for flavor of the fillets. Normal broiler breast fillets alone were used in sensory evaluation because providing panelists with both pale and normal samples could easily lead to sensory fatigue. Following cooking, breast meat was cut into one-square-inch center cut pieces. Breast fillet pieces were individually placed in a zip top plastic bag, sealed, and labeled with random numbers that corresponded to each of the five marinades. Sample packages were suspended on a metal rod over a water bath (52 C) so that submerged samples' temperature was controlled. Coded samples were served on white paper plates to fifty panelists. The five treatments were randomly ordered for presentation to each panelist and independently presented. Panelists were asked to evaluate each sample for overall flavor preference using a 9-point hedonic scale with 1=like extremely and 9=dislike extremely.

Microbial Analysis

Bacteriological analysis was conducted on raw samples using standard aerobic plate count (APC) and psychrotrophic plate count (PPC). Both PSE and normal breast fillets were tray packed separately in the Virginia Tech Muscle Foods Laboratory and stored in a 4-5 C cooler until sampled. Standard APC was determined on both pale and normal packaged fillets at 0, 3, 6, and 9 days. A sterile cotton swab was rubbed over

each sample section of breast meat in 2 similar locations per treatment inside a 10 cm^2 template, placed into 9 ml of peptone water, and broken off. Appropriate dilutions were prepared and the solution was pipetted onto Petrifilm®[10]. The Petrifilm® was incubated at either 35 C for 48 h to determine APC or 4 C for 7 days to determine PPC. Bacteria on Petrifilm® containing between 25 and 250 colony forming units (cfu) were enumerated to determine cfu/cm^2.

Statistical Analysis

Marination and TBARS:

The experimental design consisted of two replications per trial. Statistical analysis was performed using the GLM procedure (SAS Institute, 2002) to determine significance of independent variables. The means were separated using Duncan's Multiple Range Test at a significance level of $P < 0.05$.

Sensory:

The sensory data is interval and was analyzed using the ANOVA procedures of JMP IN (2001) (SAS Institute, 2001). Significance was determined at $P < 0.05$.

Microbial analysis:

This experiment was a 5x2 factorial design with 10 treatments (combinations of fillet type and days of storage). Effect of fillet type (pale, normal) and days of storage (0, 3, 6, 9) was determined by performing a log transformation of the data followed by statistical analysis using the GLM procedures of SAS 2002. Since significance between

[10] 3M Petrifilm ® Aerobic Count Plate 6400/6406/6403 Microbiology Products, St Paul, MN

fillet type and each day of storage was found, the means were separated using Duncan's Multiple Range Test at a significance level of $P < 0.05$.

RESULTS AND DISCUSSION

Experiment 1

Pale, soft, and exudative meat is a result of pH decline early postmortem while carcass temperatures are still high. This decrease in pH, caused by an accumulation of lactic acid within the muscle, attributes to the pale color and decreased WHC of this poor quality meat. The pale fillets collected at the processing plant had significantly lower pH (5.87) and higher L* values (58.82) when compared to the normal fillets (pH 6.20, L* values 52.28) prior to marination (Table 1). Previous research indicated that marination with sodium tripolyphosphates (STPP) and NaCl increased breast muscle pH, somewhat counteracting the accumulation of lactic acid from the anaerobic oxidation of glucose (Young et al., 1996; Young et al., 1999). Following marination with the twelve phosphate treatments, the pH values of the pale fillets increased, but were still significantly lower than the pH values of the marinated normal fillets, indicating that the marinades did not increase pH of the pale fillets to that of the normal fillets. These results are consistent with those of Woelfel and Sams (2001) who found that pale and normal fillets showed a significant increase in pH after marination with a pH 9 solution, with the pale fillets still exhibiting a significantly lower pH in comparison to the normal fillets.

L* value is an indicator of lightness of the fillet, with a higher L* value indicating paler fillets. The L* values of the pale fillets decreased (the fillets appeared darker) after marination with each of the 12 treatments but were still significantly lighter than the marinated normal fillets (Table 1). Even though the pale fillets did decrease in lightness, they did not improve in color to that of the normal fillets with marination. Previous

studies indicated that marination with phosphates improved color but may not improve it to that of the normal fillets (Alvarado and Sams, 2002). Results observed in this experiment are similar to that of Yang and Chen (1993) who found that after marination with trisodium phosphate broiler breast fillets had lower lightness values.

Broiler and turkey meat with low pH has been associated with low WHC (Northcutt, 1994; Allen et al., 1998). Water holding capacity is the ability to retain moisture and can be measured by marinade retention, moisture, and cook loss parameters. Marination with a pH 9 solution of salt and alkaline phosphates has been shown to increase the WHC of pale fillets and partially restore protein functionality (Woelfel and Sams, 2001). Previous studies have shown that marination with STPP significantly increases marinade absorption and retention (Young and Lyon, 1986; Young et al., 1987; Young and Lyon, 1997).

In this experiment, eight of the treatments showed no significant difference in marinade retention of pale and normal fillets (Table 1). Pale fillets marinated with treatments 1 (pH 11.9), 4 (pH 9.0), and 7 (9.8) had significantly lower marinade retention values compared to the normal fillets, while treatment 6 (9.0) alone significantly increased retention in the pale fillets compared to the normal fillets. These results agree with Allen et al. (1998) who reported that darker marinated fillets with higher pH values retained more marinade in comparison to marinated pale fillets. However, Woelfel and Sams (2001) also reported that marination with high pH phosphates increased the marinade retention of pale fillets to that of normal fillets. The majority of treatments incorporated in this study improved the marinade retention of the pale fillets to that of the normal fillets. However, combinations of different phosphate blends were used in the

treatments that could each interact with salt and produce different effects on the muscle fibers. Differences in specific activity among various phosphates have been related to their ability to penetrate or diffuse into the muscle matrix (Xiong et al., 2000).

Cook loss is another direct measure of WHC. Again, eight of the treatments showed no significant difference in cook loss when comparing pale and normal marinated fillets (Table 1). These data correspond with Young and Lyon (1997) who found that marination with STPP decreased cooking losses in pale fillets. Alvarado and Sams (2002) reported that marinating with STPP (pH 9) or other high pH (~11) phosphates decreased cook loss of pale fillets to that of normal fillets. Pale fillets marinated with treatments 8 (pH 9.5), 9 (pH 11.0), and 11 (pH 11.0) had significantly higher cook loss values compared to normal fillets marinated with the same treatments. These results agree with previous research (Allen et al., 1998; Woelfel and Sams, 2001) which indicates that light-colored breast fillets lost more moisture during cooking than normal fillets.

Marination with salt and phosphates can improve moisture retention by expanding muscle fibers, allowing more water to become entrapped within the myofibril matrix (Xiong and Kupski, 1999a). All twelve treatments revealed no significant difference when comparing pale and normal fillets for moisture (Table 1) indicating that all 12 treatments improved moisture of the pale fillets to that of the normal fillets.

These results suggest that the twelve treatments used were successful in improving the meat quality characteristics of the PSE broiler fillets. Some treatments were more successful than others in improving pH, color, and WHC of the pale fillets due to differing phosphate blends and alkaline pH levels.

Based on the results of Experiment 1 three treatments were chosen to be used in Experiment 2. Therefore, treatments 1 (pH 11.9 MP), 4 (pH 9.0 HMP, STPP), and 6 (pH 9.0 HMP, STPP agg.) were chosen and used along with two other treatments, an industry standard 2 (pH 9.7 STPP) and a newly formulated treatment 13 (pH 11.0 HMP, STPP, MP) in Experiment 2.

Experiment 2

Ultimate pH is an indicator of functionality of the breast fillets and was measured in this study to determine PSE fillets and possible increased protein functionality in marinated fillets. The pale fillets collected at the processing plant had significantly lower pH (5.79) and higher L* values (59.88) when compared to the normal fillets (pH 6.07, L* values 51.89) prior to marination (Table 2). Following marination with the five treatments, the pH values of the pale fillets increased but were still significantly lower than the pH values of the marinated normal fillets, indicating that the treatments did not increase pH of the pale fillets to that of the normal fillets. When comparing treatment effects on the pale fillets (Table 3), treatment 1 was significantly more successful than the other treatments at increasing pH. When comparing marinated normal fillets (Table 3), treatment 1 (pH 11.9/MP) again significantly ($p<0.05$) increased pH of the fillets more than the remaining treatments, while treatments 2 (pH 9.7/STPP), 4 (pH 9.0/HMP,STPP), and 6 (pH 9.0/HMP,STPP,agg) actually decreased pH after marination. Treatment 1 (pH 11.9/MP) was the most effective marinade at increasing the pH value of both pale and normal fillets, possibly because treatment 1 (pH 11.9/MP) had the highest pH and was composed of an orthophosphate, MP, which has one of the best buffering capacities compared to the other treatments (Molins, 1991).

The color of a fillet is a reflection of the muscle quality status, with PSE meat having higher L* values (increased lightness) due to the denaturation of the sarcoplasmic proteins. The L* values of the pale fillets decreased (appeared darker) after marination with each of the five treatments which indicated improved color, while normal marinated fillets, with the exception of treatment 1 (pH 11.9/MP), increased in lightness (Table 2). This increase in lightness of the normal fillets is expected and possibly due to the increase in extracellular water as a result of the marination process. Young et al. (1996) and Allen et al. (1998) have reported that marination with STPP and NaCl showed no color improvements or actually increased the lightness of the fillets, respectively. Treatments 4 (pH 9.0/HMP,STPP) and 6 (pH 9.0/HMP,STPP,agg) increased the L* value of the normal fillets and decreased the L* value of the pale fillets so that there was no significant difference between color of pale and normal fillets after marination (Table 2). One thought is that treatments 4 (pH 9.0/HMP,STPP) and 6 (pH 9.0/HMP,STPP,agg) contained the greatest percentage of HMP, which works well at sequestering alkaline earth metals that can lead to discoloration.

The a* value is a measurement of the redness of the fillet. There were no significant differences in a* value in any of the normal or any of the pale fillets prior to or following marination (Table 3). However, by treatments, the pale fillets had a significantly lower a* value when compared to the normal fillets in each treatment before marination (Table 2). Following marination, the a* values for the pale fillets marinated with each treatment (except treatment13 (pH 11.0/HMP,STPP,MP)) were not significantly different from those of the normal fillets indicating marination decreased the level of difference between pale and normal fillets. The a* values of normal marinated

fillets decreased following marination in all the treatments as did the pale fillets, with the exception of treatment 2 (pH 9.7/STPP). Allen et al. (1998) found that marination decreased both the a* and b* values of both pale and normal fillets. Young and Lyon (1997) reported that treatment with STPP significantly reduces a* value, or redness, of broiler breast fillets.

The b* value measures the yellowness of the fillet. There were no significant differences in b* value in any of the pale or any of the normal fillets prior to marination (Table 3). Following marination, treatment 4 significantly increased the yellowness of the pale fillets and treatments 2 (pH 9.7/STPP), 4 (pH 9.0/HMP,STPP) and 6 (pH 9.0/HMP,STPP,agg) significantly increased the yellowness of the normal fillets compared to the other treatments. Treatment 1 (pH 11.9/MP) significantly decreased the yellowness of both pale and normal fillets while treatment 6 (pH 9.0/HMP,STPP,agg) significantly decreased the yellowness of the pale fillets only. By treatments, the pale fillets had significantly higher b* values than the normal fillets premarination (Table 2). Following marination with treatments 1 (pH 11.9/MP) and 2 (pH 9.7/STPP) pale and normal fillets were not significantly different in yellowness, indicating improved color of pale fillets to that of normal fillets. Treatments 4 (pH 9.0/HMP,STPP) and 6 (pH 9.0/HMP,STPP,agg) significantly decreased b* values of pale fillets to lower than normal fillets. Treatment 13 (pH 11.0/HMP,STPP,MP) increased the b* value of the pale fillets significantly more than the normal fillets. As a note, lightness of the fillet (L* value) is an important quality attribute for consumers and is more discernable than changes in a* or b* values.

Water holding capacity parameters of marinade pickup and retention as well as cook loss were determined. The polyelectrolyte behavior of phosphates promotes water retention. This characteristic of phosphates allows them to attach themselves to positively charged sites of proteins so that they increase water binding (Molins, 1991). All treatments performed equally for marinade pickup and retention of pale and normal fillets, indicating that marination with these five treatments improved pickup and retention of pale fillets to that of normal fillets (Table 5). Comparing treated normal fillets, treatments 1 (pH 11.9/MP), 2 (pH 9.7/STPP), and 13 (pH 11.0/HMP,STPP,MP) significantly increased marinade pickup compared to the other treatments. One possible thought behind this is that treatment 1 (pH 11.9) contained monophosphate, treatment 2 (pH 9.7) contained sodium tripolyphosphate and treatment 13 (pH 11.0) contained both sodium tripolyphosphate and monophosphate, which are either ortho- or polyphosphates; both of which can have several negative charges and are capable of opening up the muscle matrix to a greater extent than the other treatments. There were no differences, by treatment, in marinade retention for normal fillets. Treatments 1 (pH 11.9/MP), 4 (pH 9.0/HMP,STPP), and 13 (pH 11.0/HMP,STPP,MP) significantly decreased cook loss in pale fillets while treatment 2 (pH 9.7/STPP) had the highest cook loss compared to the other treatments. Treatment 1 (pH 11.9/MP) alone significantly decreased cook loss in normal fillets. Treatments 4 (pH 9.0/HMP,STPP), 6 (pH 9.0/HMP,STPP,agg), and 13 (pH 11.0/HMP,STPP,MP) improved cook loss of pale fillets to that of normal fillets, indicating that marination with these treatments will increase the yield of pale fillets to that of normal fillets due to decreased cooking losses (Table 5). Treatments 1 (pH 11.9/MP) and 2 (pH 9.7/STPP) resulted in significantly higher cook loss values in pale

fillets compared to normal fillets. The differences in cook loss with treatment 1 were possibly due to the major reduction in cook loss of the normal fillets.

Thiobarbituric Acid Reactive Substances

Cooked meats can develop oxidative off-flavors during refrigerated storage (Ang and Young, 1987). One factor affecting the deterioration of meat and the subsequent off flavors is lipid oxidation. Polyphosphate salts have been shown to retard these oxidative changes (Ang and Young, 1987) by exhibiting antioxidant activity as metal-sequestering agents. However, studies have also shown that salt accelerates lipid oxidation, thereby reducing the protection afforded by phosphates (Molins, 1991). There was no significant difference in any of the 5 treatments for pale or normal fillets for TBARS values for days 0, 2, or 4 (Table 6). Lipid oxidation occurs at a faster rate with low water holding capacity, and PSE meat has lower pH and WHC than normal fillets. Oxidation can also increase as pH increases. Therefore, the high pH marinades had no effect on the development of oxidation in either pale or normal fillets.

Sensory

Sensory perception is of utmost importance in determining consumer satisfaction. Pale, soft, and exudative meat is characterized by poor texture and low moisture that is a result of a decrease in pH early postmortem that leads to protein denaturation. Marinating PSE meat with a combination of salt and phosphates has been shown to increase WHC and tenderness (Lyon and Lyon, 2000). The phosphate-salt combination has been shown to improve tenderness, juiciness, flavor and overall sensory impression of tumble marinated breast meat (Lyon, 1983; Lyon and Hamm, 1986).

This study consisted of fifty panelists, 54% female and 46% male. The majority of panelists (64%) were between 18 and 25 years of age followed by 20% in the 26 to 40 range and the remaining 16% were between 40 and 60. Ninety percent of the panelists consumed chicken a few times a week or more; 86% purchased chicken a few times a month or more, and 74% used chicken in their meals a few times a week or more.

In this experiment, panelists did not significantly prefer any one treatment over another for normal marinated fillets (Table 7). The breast fillet samples for all treatments averaged a 3.41 on a 9-point hedonic (1=like extremely, 9=dislike extremely) scale for overall flavor acceptability (Figure 1), indicating that all five fillets were "liked moderately". Xiong and Kupski (1999b) conducted a taste panel that detected little differences between high and low level phosphate treatments and considered tripolyphosphates (TPP) ≥ pyrophosphates (PP) > HMP at improving juiciness, saltiness, and overall flavor intensity at $p < 0.10$.

Microbial Analysis

Microbial load of raw broiler meat can have a significant effect on shelf-life. Conflicting results have been obtained concerning the shelf-life enhancing properties of phosphates on Gram-negative microflora of poultry (Allen et al., 1998). It is believed that phosphates act as growth inhibitors of certain food spoilage microorganisms due to their ability to sequester calcium, magnesium, and iron; all minerals essential for microbial growth (Molins, 1991). In this study there was no obvious trend for any treated PSE or normal fillets in decreasing or enhancing microbial growth (Figures 2-6). There are a variety of factors involved that interact to affect microbial growth rate including type of phosphate used, meat pH, ionic strength, other inhibitors, temperature and

presence of metal ions (Allen et al., 1998). Perhaps that is why there was no obvious trend with any of the treatments. Treatment 1 (pH 11.9/MP) had slightly higher aerobic plate counts when compared to the other treatments over time (Figures 7 and 8). This observation could be due to treatment 1 (pH 11.9/MP) having a higher pH value following marination compared to the remaining treatments. A higher pH usually permits more growth of microorganisms compared to lower pH values. Therefore, this trend was expected. Newton and Gill (1981) found that increased pH reduces the lag phase time needed for growth of spoilage microorganisms. Davies and Board (1998) also reported that meat with high ultimate pH (> 6.0) favors rapid microbial growth. By day 12 all treatments were considered spoiled (> 10^8 cfu/g of meat). The psychrotrophic counts were excluded from the results of this experiment because after 7 days of storage at 4 C there was no growth for all 5 treatments for either fillet type. Results may have been different if incubation time was increased from 7 to 10 days.

CONCLUSION

In conclusion, the marinades used in Experiment 2 increased the pH, decreased the L* values of the pale fillets, and improved water holding capacity. There was no difference in oxidation or shelf-life trends in either the pale or normal fillets marinated with each of the five treatments. There were also no significant differences in overall flavor preference for any of the five phosphate treatments. Therefore, marination with high pH phosphates can reduce the undesirable characteristics of PSE meat without increasing the development of oxidation, altering flavor, or reducing shelf-life.

The results of this study indicate that utilization of high pH phosphates improve poor quality meat such as PSE to that of normal levels. This improvement leads to a

higher pH and water holding capacity which can improve processor yield and an improvement in appearance of the meat by decreasing paleness for increased consumer satisfaction. Since a genetic solution to PSE meat in broilers may take years to develop, the use of high pH phosphates could be used as a remediation technique for poultry processors currently concerned with the negative impacts of PSE broiler meat on yield and consumer satisfaction.

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APPENDIX I: Tables

Table 1. Experiment 1 mean comparisons of meat quality parameters of pale (P) and normal (N) broiler breast fillets marinated with 12 different treatments

Treatment	Treatment pH	Meat Type	pH (before)	pH (after)	L* (before)[1]	L* (after)[1]	Cook Loss (%)	Retention (%)	Moisture (%)
2	9.7	P	5.78^{by}	5.91^{bx}	61.10^{ax}	56.86^{ay}	25.82^{a}	99.12^{a}	72.57^{a}
	(standard)	N	6.13^{ax}	6.36^{ay}	50.80^{by}	53.24^{bx}	28.12^{a}	97.93^{a}	71.91^{a}
1	11.9	P	5.73^{by}	6.34^{bx}	59.91^{ax}	54.61^{ay}	23.95^{a}	99.62^{b}	73.96^{a}
		N	6.17^{ay}	6.58^{ax}	50.07^{b}	49.83^{b}	21.90^{a}	99.77^{a}	73.83^{a}
9	11	P	5.68^{by}	5.87^{bx}	58.86^{a}	57.35^{a}	24.40^{a}	98.95^{a}	83.53^{a}
		N	6.03^{a}	6.13^{a}	51.26^{by}	55.22^{bx}	22.33^{b}	98.81^{a}	89.18^{a}
10	11	P	5.85^{by}	6.01^{bx}	60.68^{ax}	57.04^{ay}	27.39^{a}	99.00^{a}	72.37^{a}
		N	6.26^{a}	6.33^{a}	49.30^{by}	53.21^{bx}	24.38^{a}	98.23^{a}	72.62^{a}
11	11	P	5.86^{b}	5.94^{b}	60.03^{ay}	57.78^{ax}	27.85^{a}	99.30^{a}	72.05^{a}
		N	6.19^{a}	6.22^{a}	50.25^{by}	55.27^{bx}	24.38^{b}	99.30^{a}	73.42^{a}
12	11	P	5.82^{by}	5.92^{bx}	60.07^{ax}	56.81^{ay}	26.76^{a}	99.18^{a}	72.07^{a}
		N	6.23^{a}	6.22^{a}	50.28^{by}	54.71^{bx}	26.69^{a}	99.06^{a}	73.48^{a}
7	9.8	P	5.88^{b}	5.85^{b}	60.54^{ax}	57.69^{ay}	22.66^{a}	97.25^{a}	72.18^{a}
		N	6.19^{a}	6.20^{a}	50.15^{by}	53.47^{bx}	24.69^{a}	99.16^{a}	72.22^{a}
8	9.5	P	5.85^{bx}	5.80^{by}	61.16^{ax}	56.80^{ay}	26.62^{a}	99.44^{a}	73.22^{a}
		N	6.18^{a}	6.17^{a}	50.36^{by}	53.47^{bx}	18.74^{b}	99.25^{a}	74.14^{a}
4	9.0	P	5.79^{by}	5.90^{bx}	59.49^{ax}	56.76^{ay}	23.48^{a}	99.06^{b}	73.68^{a}
		N	6.12^{a}	6.14^{a}	49.69^{by}	54.53^{bx}	25.05^{a}	99.53^{a}	72.79^{a}
6	9.0	P	5.71^{by}	5.83^{bx}	60.93^{ax}	57.61^{ay}	23.78^{b}	99.35^{a}	73.65^{a}
		N	6.13^{a}	6.03^{a}	50.45^{by}	57.64^{bx}	27.94^{a}	98.67^{a}	72.95^{a}
5	8.5	P	5.88^{bx}	5.74^{by}	60.47^{ax}	56.15^{ay}	25.78^{a}	99.36^{a}	72.13^{a}
		N	6.21^{a}	6.22^{a}	48.34^{by}	56.67^{bx}	23.87^{a}	99.07^{a}	74.41^{a}
3	7.0	P	5.74^{by}	5.97^{bx}	60.83^{ax}	57.35^{ay}	24.61^{a}	98.81^{a}	73.84^{a}
		N	6.14^{ay}	6.22^{ax}	50.48^{by}	52.62^{bx}	24.34^{a}	98.92^{a}	73.32^{a}

[a,b] Means with different superscripts within a column and treatment are significantly different ($P<0.05$)
[x,y] Means with different superscripts within a row and a parameter are significantly different ($P<0.05$)
[1]L* value is a measurement of lightness of the fillet

Table 2. Comparison of means of meat quality parameters in pale (P) and normal (N) marinated broiler breast fillets

Treatment	pH 9.7	pH	pH	L*	L*	a*	a*	b*	b*
2	STPP	(before)	(after)	(before)[1]	(after)[1]	(before)[2]	(after)[2]	(before)[3]	(after)[3]
N	(industry	6.08^{a}	6.04^{a}	51.98^{ax}	54.60^{ay}	3.36^{ax}	2.27^{y}	3.73^{ax}	5.54^{y}
P	standard)	5.80^{bx}	5.92^{by}	59.80^{bx}	56.01^{by}	2.17^{b}	2.46	4.99^{bx}	5.61^{y}
Treatment	pH 11.9								
1	MP								
N		6.06^{ax}	6.26^{ay}	51.98^{a}	51.12^{a}	3.61^{ax}	2.3^{y}	3.8^{a}	3.43
P		5.83^{bx}	6.05^{by}	59.58^{bx}	54.85^{by}	2.19^{b}	2.09	4.63^{b}	4.16
Treatment	pH11.0								
13	HMP,STPP,MP								
N		6.07^{a}	6.07^{a}	51.58^{ax}	54.10^{ay}	3.48^{ax}	2.81^{ay}	3.72^{a}	4.08^{a}
P		5.79^{bx}	5.79^{bx}	60.29^{bx}	57.26^{by}	2.38^{b}	2.05^{b}	4.81^{b}	5.12^{b}
Treatment	pH 9.0								
4	HMP,STPP								
N		6.06^{a}	5.99^{a}	52.02^{ax}	55.27^{y}	3.46^{ax}	2.33^{y}	3.94^{ax}	5.83^{ay}
P		5.74^{bx}	5.82^{by}	60.31^{bx}	54.76^{y}	2.58^{bx}	1.97^{y}	4.87^{bx}	4.11^{by}
Treatment	pH 9.0								
6	HMP,STPP,agg								
N		6.11^{ax}	5.97^{ay}	51.83^{ax}	54.58^{y}	3.72^{ax}	2.65^{y}	3.94^{ax}	5.31^{ay}
P		5.76^{b}	5.83^{b}	59.49^{bx}	54.34^{y}	2.41^{b}	2.31	4.5^{b}	4.39^{b}

^{a,b} Means with different superscripts within a column and treatment are significantly different ($P<0.05$)

^{x,y} Means with different superscripts within a row and a parameter are significantly different ($P<0.05$)

[1]L* value indicates the lightness of the fillet (range= 0 to100)

[2]a* value indicates the redness of the fillet (range = -60 to 60)

[3]b* value indicates the yellowness of the fillet (range = -60 to 60)

Table 3. Treatment comparisons of pH and color in pale and normal marinated broiler breast fillets

Pale Treatment	pH (before)	pH (after)	L* (before)[1]	L* (after)[1]	a* (before)[2]	a* (after)[2]	b* (before)[3]	b* (after)[3]
2 (pH 9.7/STPP)	5.80	5.92[b]	59.8	56.01[ab]	2.17	2.46	4.99	5.61[b]
1 (pH 11.9/MP)	5.83	6.05[a]	59.58	54.85[bc]	2.19	2.09	4.63	4.16[c]
13 (pH 11.0 HMP,STPP,MP)	5.79	5.89b[c]	60.29	57.26[a]	2.38	2.05	4.81	5.12[b]
4 (pH 9.0/HMP,STPP)	5.75	5.82[c]	60.31	54.76[bc]	2.58	1.97	4.87	6.05[a]
6 (pH 9.0 HMP,STPP,agg)	5.76	5.83[c]	59.49	54.34[c]	2.41	2.31	4.5	4.39[c]
Normal Treatment								
2 (pH 9.7/STPP)	6.08	6.04[bc]	51.98	54.60[ab]	3.36	2.27	3.73	5.54[a]
1 (pH 11.9/MP)	6.05	6.26[a]	51.99	51.12[c]	3.62	2.30	3.80	3.43[c]
13 (pH 11.0 HMP,STPP,MP)	6.07	6.11[b]	51.58	54.10[b]	3.48	2.81	3.72	4.08[b]
4 (pH 9.0/HMP,STPP)	6.06	5.99[c]	52.02	55.27[a]	3.46	2.33	3.94	5.83[a]
6 (pH 9.0 HMP,STPP,agg)	6.11	5.97[c]	51.83	54.58[ab]	3.72	2.65	3.94	5.31[a]

[a-d] Means with different superscripts in a column within a parameter and within fillet type (pale/normal) are significantly different ($P<0.05$)

[1]L* value indicates the lightness of the fillet (range= 0 to100)

[2]a* value indicates the redness of the fillet (range = -60 to 60)

[3]b* value indicates the yellowness of the fillet (range = -60 to 60)

Table 4. Treatment comparisons of water-holding capacity parameters of pale and normal marinated broiler breast fillets

Pale Treatment	Blend	Pickup (%)	Retention (%)	Cook Loss (%)
2	(pH 9.7/STPP)	17.74	99.16	29.85[a]
1	(pH 11.9/MP)	17.27	99.72	20.45[c]
13	(pH 11.0/HMP,STPP,MP)	17.08	99.65	23.59[bc]
4	(pH 9.0/HMP,STPP)	16.84	98.90	21.73[bc]
6	(pH 9.0/HMP,STPP,agg)	15.78	99.59	24.94[b]
Normal Treatment				
2	(pH 9.7/STPP)	17.30[ab]	98.98	21.71[ab]
1	(pH 11.9/MP)	17.68[ab]	97.87	16.65[c]
13	(pH 11.0/HMP,STPP,MP)	18.09[a]	99.34	19.77[b]
4	(pH 9.0/HMP,STPP)	15.68[c]	96.95	22.04[ab]
6	(pH 9.0/HMP,STPP,agg)	16.22[bc]	99.68	22.93[a]

[a-c] Means with different subscripts within a column and fillet type are significantly different ($P<0.05$)

Table 5. Comparison of means of water-holding capacity parameters in pale (P) and normal (N) marinated broiler breast fillets

Treatment	Blend	Fillet Type	Pickup (%)	Retention (%)	Cook Loss (%)
2	(pH 9.7/STPP)	N	17.30	98.98	21.71[a]
		P	17.71	99.16	29.85[b]
1	(pH 11.9/MP)	N	17.67	97.87	16.65[a]
		P	17.27	99.72	20.45[b]
13	(pH 11.0/HMP,STPP,MP)	N	18.09	99.34	19.77
		P	17.08	99.65	23.59
4	(pH 9.0/HMP,STPP)	N	15.68	96.95	22.04
		P	16.84	98.90	21.73
6	(pH 9.0/HMP,STPP,agg)	N	16.22	99.68	22.93
		P	15.78	99.59	24.94

[a,b] Means with different subscripts within a column and treatment are significantly different ($P<0.05$)

Table 6. Comparisons of thiobarbituric acid reactive substances (TBARS) (mg/kg) in pale and normal fillets treated with 5 different phosphates

Pale Treatment	Blend	TBARS (day 0)	TBARS (day 2)	TBARS (day 4)
2	(pH 9.7/STPP)	2.78	4.12	4.61
1	(pH 11.9/MP)	2.17	3.22	4.78
13	(pH 11.0/HMP,STPP,MP)	2.02	3.50	4.94
4	(pH 9.0/HMP,STPP)	2.07	4.06	3.93
6	(pH 9.0/HMP,STPP,agg)	1.68	2.93	4.01
Normal Treatment				
2	(pH 9.7/STPP)	2.18	4.6	4.62
1	(pH 11.9/MP)	1.76	3.92	3.7
13	(pH 11.0/HMP,STPP,MP)	1.73	4.02	6.46
4	(pH 9.0/HMP,STPP)	1.99	4.17	6.63
6	(pH 9.0/HMP,STPP,agg)	2.02	4.24	6.79

Table 7. Mean sensory scores on a 9-point hedonic scale (1=like extremely, 9=dislike extremely) for overall preference of normal fillets marinated with 5 different phosphates

Treatment	Hedonic Scale Value[1]
2 (pH 9.7/STPP)	3.78
1 (pH 11.9/MP)	3.44
13 (pH 11.0/HMP,STPP,MP)	3.04
4 (pH 9.0/HMP,STPP)	3.42
6 (pH 9.0/HMP,STPP,agg)	3.38

n = 50

[1] hedonic scale scores 1 to 9 with 1=like extremely, 9=dislike extremely; average score of 3.41 for "liked moderately"

APPENDIX II: Figures

Chicken Breast Fillet

1. Gender: □ male □female

2. Age: □18-25 □26-40 □40-60 □60+

3. How often do you consume chicken?
□few times a year □ few times a month □few times a week □many times a week

4. How often do you purchase chicken?
□few times a year □few times a month □few times a week □many times a week

5. How often do you use chicken in meals?
□few times a year □few times a month □few times a week □many times a week

Please taste the sample. Mark the box next to the rating that best describes your feelings about the flavor/taste of the chicken breast fillet.

Hedonic Rating for Flavor:

□ Like extremely
□ Like very much
□ Like moderately
□ Like slightly
□ Neither like nor dislike
□ Dislike slightly
□ Dislike moderately
□ Dislike very much
□ Dislike extremely

Comments: _____

_____

_____

Figure 1. Example of the broiler breast fillet scorecard used to determine overall flavor preference using a 9-pt hedonic scale

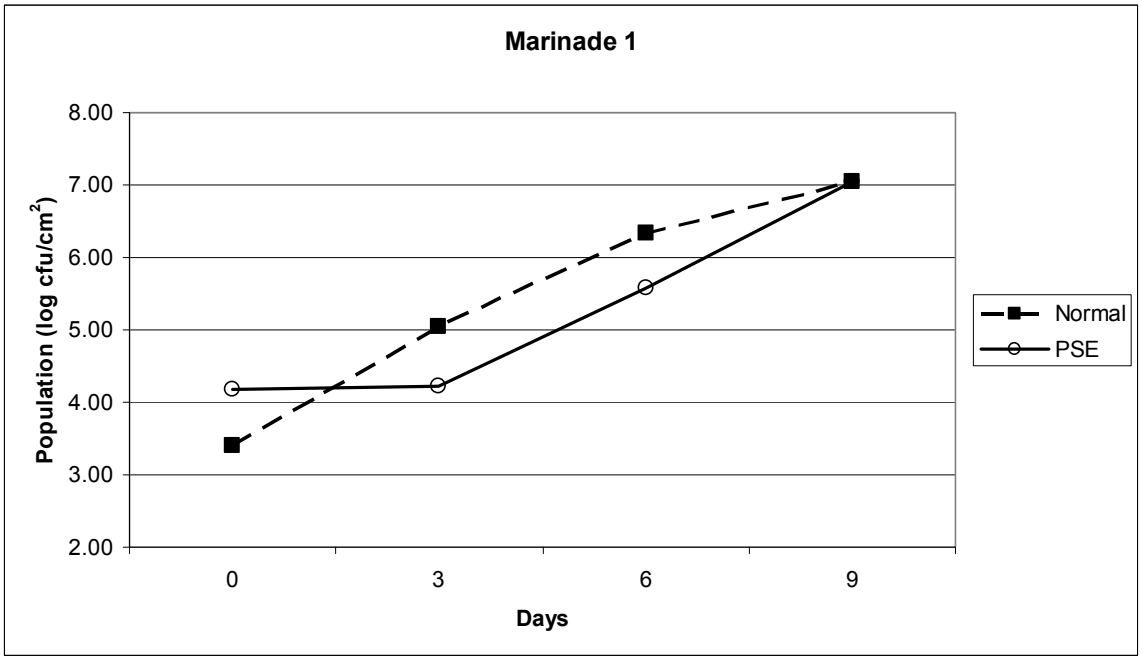

Figure 2. Growth of aerobic mesophilic bacteria on pale and normal fillets marinated with treatment 1 (pH 11.9/MP) over nine days

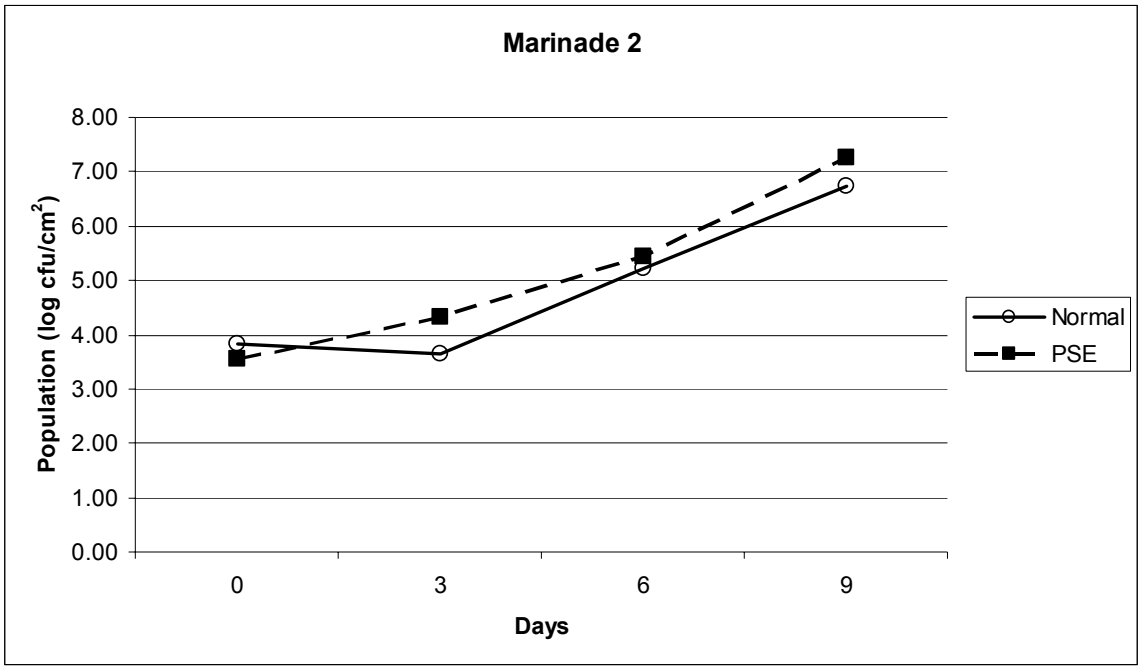

Figure 3. Growth of aerobic mesophilic bacteria for pale and normal fillets marinated with treatment 2 (pH 9.7/STPP) over nine days

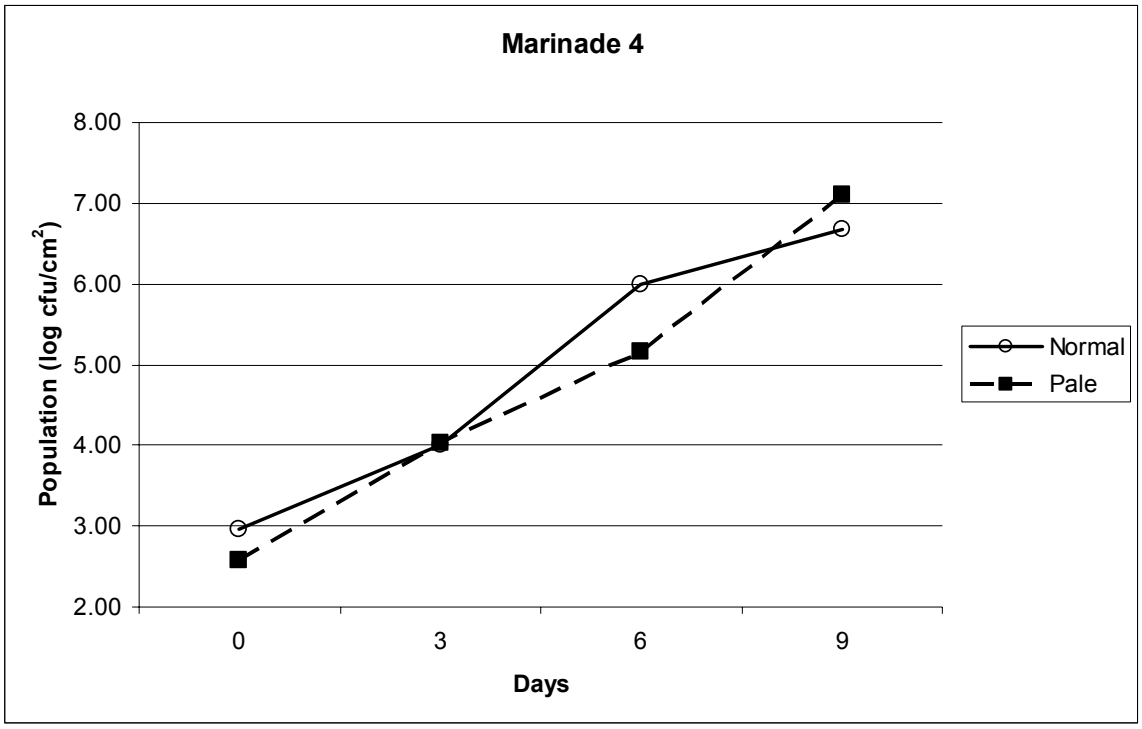

Figure 4. Growth of aerobic mesophilic bacteria for pale and normal fillets marinated with treatment 4 (pH 9.0/HMP,STPP) over nine days

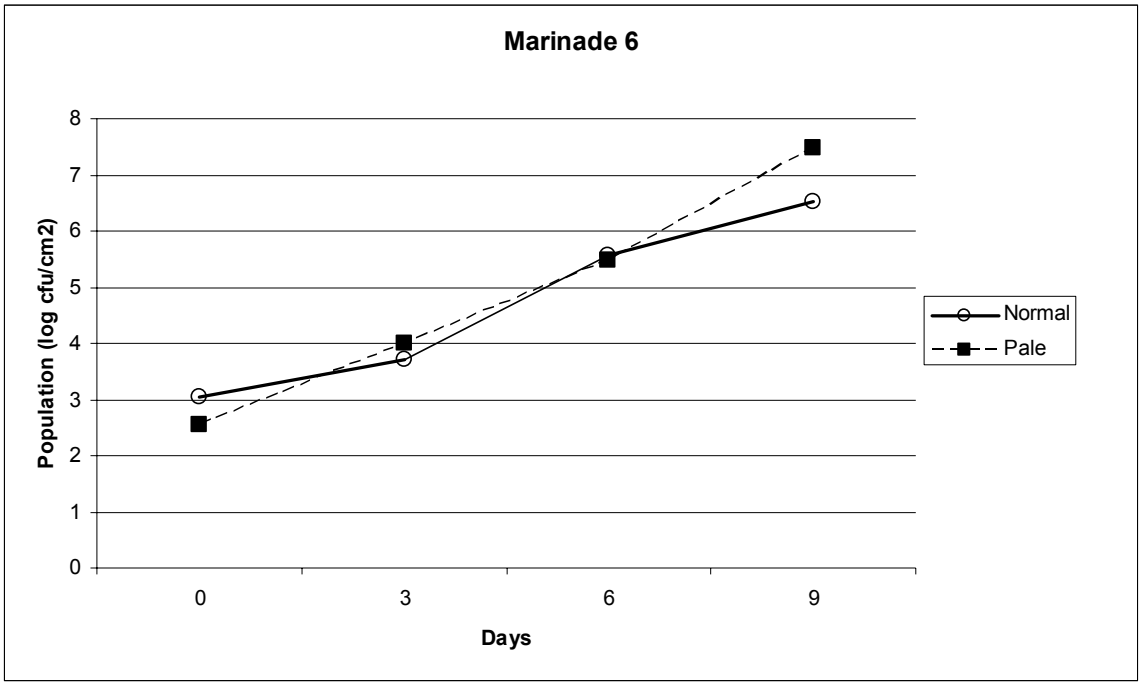

Figure 5. Growth of aerobic mesophilic bacteria for pale and normal fillets marinated with treatment 6 (pH 9.0/HMP,STPP,agg) over nine days

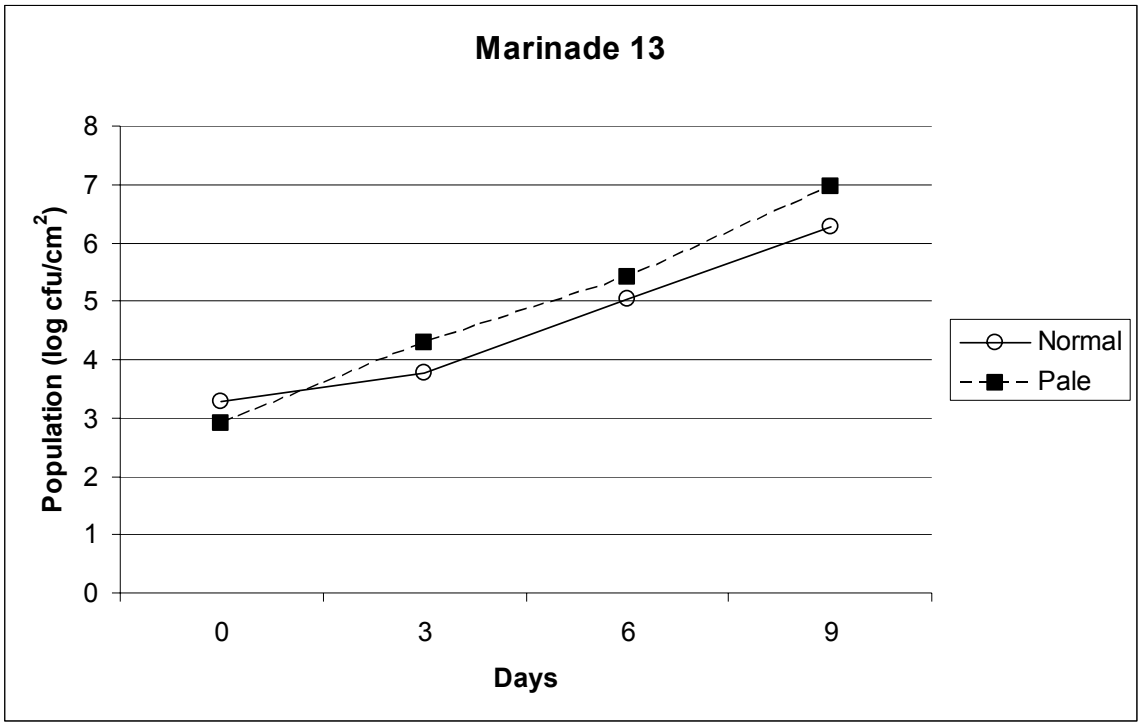

Figure 6. Growth of aerobic mesophilic bacteria for pale and normal fillets marinated with treatment 13 (pH 11.0/HMP,STPP,MP) over nine days

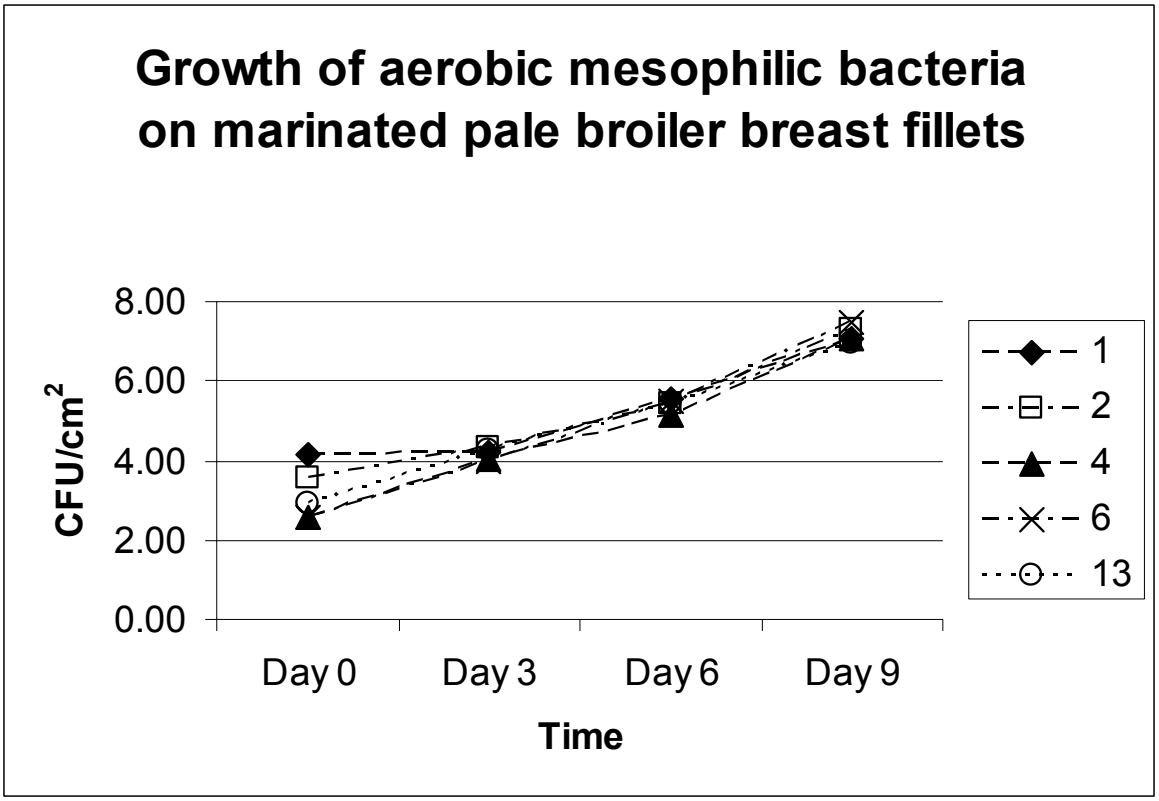

Figure 7. Comparative growth of aerobic mesophilic bacteria on pale broiler breast fillets marinated with five different phosphate treatments over 9 days (1=pH 11.9/MP, 2=pH 9.7/STPP, 4=pH 9.0 HMP,STPP, 6=pH 9.0/HMP,STPP,agg, 13=pH 11.0/HMP,STPP,MP)

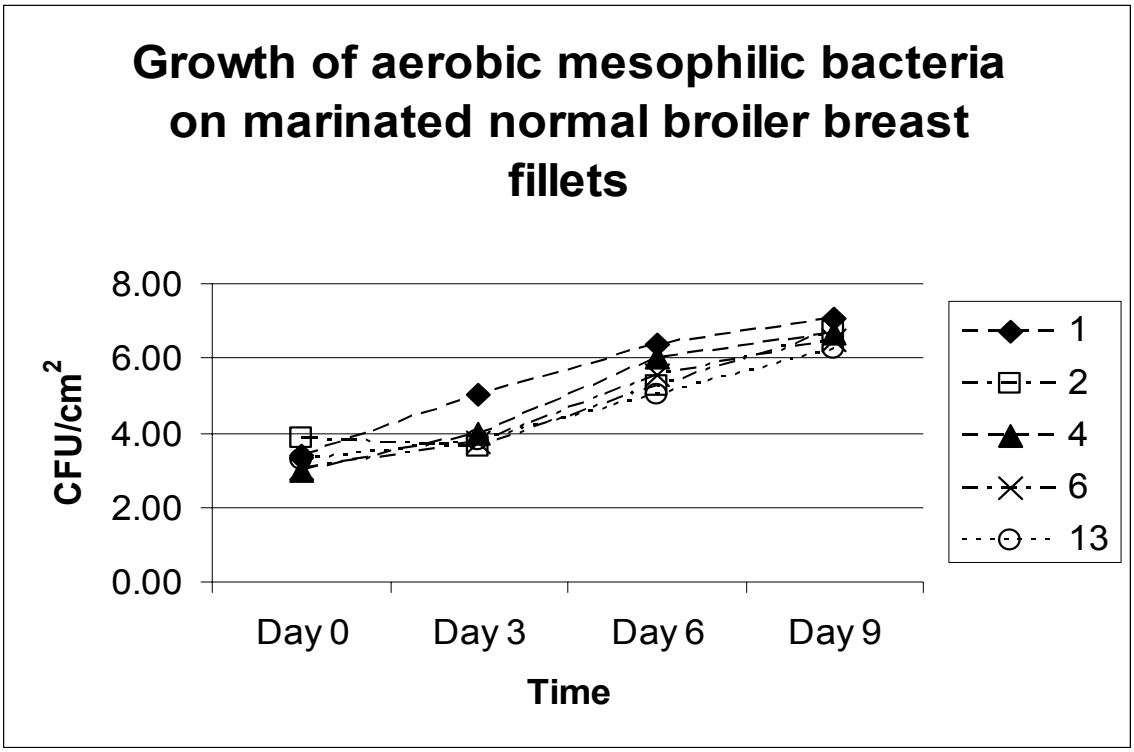

Figure 8. Comparative growth of aerobic mesophilic bacteria on normal broiler breast fillets marinated with five different phosphate treatments over 9 days (1=pH 11.9/MP, 2=pH 9.7/STPP, 4=pH 9.0 HMP,STPP, 6=pH 9.0/HMP,STPP,agg, 13=pH 11.0/HMP,STPP,MP)

VITA:

Valerie Gorsuch was born in Chincoteague, VA where she attended Chincoteague Elementary. She changed schools at the start of middle school and graduated from Broadwater Academy in Exmore, VA in 1997. Following high school, she attended Virginia Polytechnic Institute and State University receiving her Bachelor's degree in Food Science and Technology with a Minor in Chemistry in 2001. She received the Outstanding Transfer Student Award and the Outstanding Academic Achievement Award in FST as an undergraduate. While in the Food Science Department Valerie was an active member of the Food Science Club for 2 years as a member and serving as secretary her senior year.

Following graduation, Valerie decided to stay at Virginia Tech and work towards a Master's degree in Food Science and Technology. She started graduate school in the Fall of 2001. Remaining at Virginia Tech, Valerie stayed an active member of the Food Science Club and served as president for her 2001-2002 and 2002-2003 years as a graduate student. She was also a student representative for the Food Science and Technology department's Graduate committee. She received the Marvin Poster Scholarship and the Faculty Award and Scholarship for Outstanding Graduate student. Valerie was also a student member in the Institute of Food Technologists (IFT) and the Poultry Science Association (PSA).